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THE DESIGN AND OPERATION OF A WATER PERMEABILITY SYSTEM TO TEST ROCK CORES AT MEDIUM PERSSURE

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THE DESIGN AND OPERATION OF A WATER PERMEABILITY SYSTEM TO TEST ROCK CORES AT MEDIUM PRESSURE

by

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SUMMARY

The equipment described in this report has been successfully used to determine the permeability of rock core specimens at various stress levels. The equipment was built to satisfy the increasing test requirements of the Rock Mechanics Laboratory.

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CONCEPTION ET MODE DE FONCTIONNEMENT D'UN SYSTÈME POUR MESURER LA PERMÉABILITÉ D'ÉCHANTILLONS DE ROCHE À MOYENNE PRESSION

par

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RÉSUMÉ

L'équipement décrit dans ce rapport à été utilisé avec succès pour établir la perméabilité d'échantillons de roche soumis à divers essais de résistance. L'équipement à été monté pour répondre aux besoins de contrôle croissant du Laboratoire de la mécanique des roches.

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1.0 INTRODUCTION

The migration of methane gas and seepage of groundwater through underground rock formations is of concern to the mining engineer from a safety point of view. Both events are controlled by the permeability of the rock formation.

Intact rock core may be tested by the permeability apparatus, newly developed at CANMET's Mining Research Laboratory (Fig.1). The apparatus is designed to permit the application of lithostatic and pore pressures of 35 MPa and 18 MPa, respectively. It accommodates 45 mm diameter core specimens with lengths from 45 mm to 100 mm. Water pressures, both upstream and downstream, can be varied independently. The flow rates are measured by a vertical, volume calibrated, bubble tube. A commercially available pressure vessel is used for lithostatic con- ditions. The vessel is equipped with three heater straps which are used for elevated temperature tests. The constant water head permeability test method is used with this equipment. The other permeability equipment used in the laboratory [1] is based on the transient pulse technique [2].

2.0 TEST APPARATUS

2.1 LITHOSTATIC PRESSURE VESSEL

The pressure chamber consists of a commercially-available stainless steel pressure vessel [3]. It is machined to receive a seal plug which is secured to the vessel body by ten socket cap screws. The plug has two thru-ports that accommodate upstream and downstream pore pressure tubing from the sample. A side port on the pressure vessel allows the entrance of silicone oil pressurizing fluid.

The pressure vessel is enclosed by three, 1000 Watt, 110 Volt, single phase, 60 cycle, jacket type heaters. Any, or all, of the heaters may be used to control temperature levels and heating rates. The temperature is indicated
by means of a thermocouple, located within the thermocouple well and connected to a voltmeter and/or Omega time base recorder. The vessel is rated to 343°C.

2.2 SAMPLE ASSEMBLY

The test samples, having ends parallel to within 0.01 cm, are encased in thin-wall annealed copper sleeves of approximately 0.15 mm thickness. The

inside diameter of the sleeve is close to that of the sample. Undersized sample diameters may be built up by Teflon tape.

The rock/jacket assembly is mechanically sealed by forcing steel rings over conical surfaces of the end plugs. This sealing arrangement prevents the confining pressure fluid from entering the pores of the rock.

To allow uniform distribution of the pore fluid across the specimen, fine filter paper is placed at each end between the rock and metal plugs.

2.3 CONFINING PRESSURE SYSTEM

Confining pressure is generated by a hydraulic hand pump and maintained by a manually operated piston screw pump. Up to 35 MPa pressure of the silicone oil confining fluid can be maintained in this manner. Volume fluctuations due to the heating or cooling of silicone oil are corrected by the incorporation of a bleeder valve and silicone oil reservoir. Confining fluid temperature is monitored as described under item 2.1. Confining pressure (lithostatic) is monitored by means of a 35 MPa bourdon pressure gauge.

2.4 PORE PRESSURE SYSTEM

Pore pressure (refer to Fig. 2) is provided with a manually-operated piston screw pump. The pump is pressure rated to 35 MPa and has a capacity of 60 cm^2. Upstream pressure is monitored by a digital pressure transducer and/or a Bourdon type pressure gauge, depending on the required resolution. The screw pump can be isolated from the upstream pressure gauge as can the water reservoir. The introduction of controlled downstream pressures is facilitated by a bypass line and valve. The downstream line is connected to a Bourdon type pressure gauge and is ported to an outlet line and vertical bubble tube, either of which may be isolated by valves. The outlet line facilitates the bleeding off of downstream pressures or evacuation of the rock specimen by connecting a vacuum pump. The evacuation circuit also incorporates a sediment chamber and vacuum gauge. The bubble tube is graduated in 0.01 cm^3 to a maximum of 0.5 cm^3 and facilitates flow measurements when readings are taken versus time. The upper end of the tube is vented to the atmosphere. All valves and pressure tubing were assembled using stainless steel only.

3.0 TEST PROCEDURE

3.1 DENSITY MEASUREMENTS

Prior to jacketing, rock specimens are mechanically ground to within specified tolerances, measured, and oven-dried prior to weighing. Oven heating and cooling rates are set at less than 0.35°C per minute, to a maximum of 63°C, in order to minimize thermal cracking [4]. Sample density is calculated from the weight and measured dimensions.

3.2 SAMPLE HOLDER ASSEMBLY

Sample jacketing methods are described under item 2.2. The jacketed sample is connected to the upstream and downstream ports of the plug sample holder assembly (Fig. 3). The plug and assembly are then lowered into position over the pressure vessel. The ten screw cap bolts are torqued in position to seal the plug. Air voids are displaced from the vessel, with silicone oil, through a bolt hole in the plug.

3.3 SAMPLE EVACUATION

A lithostatic pressure, considerably less than that of the test pressure, is applied to the sample and maintained. Upstream and downstream lines from the permeability panel are connected to the vessel plug and all panel valves are shut except the sample bypass valve and the bleeder/vacuum valve. The jacketed sample is then evacuated for a four to six hour period. This procedure allows the detection of leakages within the sample jacket by monitoring the vacuum gauge, and facilitates the removal of vapour and pressure from the sample and lines prior to saturation. A sediment chamber facilitates entrapment of moisture.

3.4 SAMPLE SATURATION

After evacuation the vacuum valve is shut and the upstream valve is opened. The distilled water reservoir valve is then opened and in this way both the upstream and downstream lines (bypass valve open) are filled with water. The bleeder valve is opened first. It is closed when the remaining air is displaced. The reservoir valve is now closed and a pore pressure, approximately half the value of the confinement pressure, is applied to both upstream and downstream lines. Both the upstream and bypass valves are now

closed. The downstream line is set to a value of pore pressure somewhat less than that for the upstream line, by using the bleeder valve. Sample saturation, depending on porosity and sample length, may take anywhere from one hour to seven days. Upstream pore pressure is constantly maintained during this time. The saturation of a sample is indicated by a gradual increase in downstream pressure.

3.5 TEST MEASUREMENTS

With the sample saturated, test measurements may now be conducted. The test confining pressure is applied. The downstream pore pressure is released to zero, through the bubble tube. Upstream pore pressure is applied to the test specimen (generally not exceeding 50% of the confinement pressure value) and maintained constant. The bubble tube valve is opened and volume readings versus time are taken as water rises in the calibrated tube at a fixed temperature. Several test increments of confinement pressure and upstream pressure may be applied.

3.6 HEATED SAMPLES

The effect of elevated temperatures on the permeability of a test specimen may be investigated by use of one or all three of the inplace jacket type heaters. The system is rated to temperatures of up to 343°C. The heating rates vary with the number of jacket heaters used. Temperatures are monitored by a thermocouple located in a thermocouple well in the plug. The thermocouple is connected to a time base Omega recorder.

Volumetric expansion of the confinement fluid is controlled by a bleeder valve in line with the silicone oil reservoir.

4.0 DATA TREATMENT

Sample permeability is calculated based on Darcy's law for an incompressible liquid as follows:

$$K = \frac{\mu q L}{A (P1 - P2)}$$

k = Permeability (darcies)

μ = Liquid viscosity (centipoise)

q = Incompressible liquid volume flow rate (cm^3/sec)

L = Length of core sample (cm)

A = Cross-sectional area (cm^2)

$P_1 - P_2$ = Δp, pressure difference from inflow to outflow face of sample (standard atmospheres absolute)

Bubble tube readings are restricted to an eight hour limit and 0.01 cm^3 minimum. The effects of evaporation are significant for lower readings of volume and longer periods of time.

5.0 CONCLUSION

A water permeability test apparatus has been developed and successfully used to obtain water permeabilities, in the millidarcy range, for rock core specimens.

This apparatus will aid in further expanding the capabilities of the Rock Mechanics Laboratory.

6.0 REFERENCES

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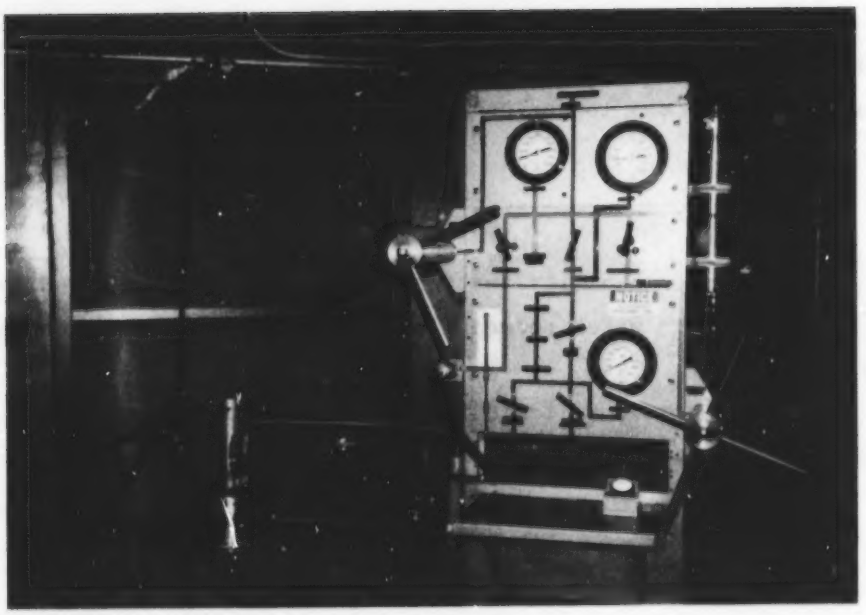

Fig. 1 - Permeability apparatus

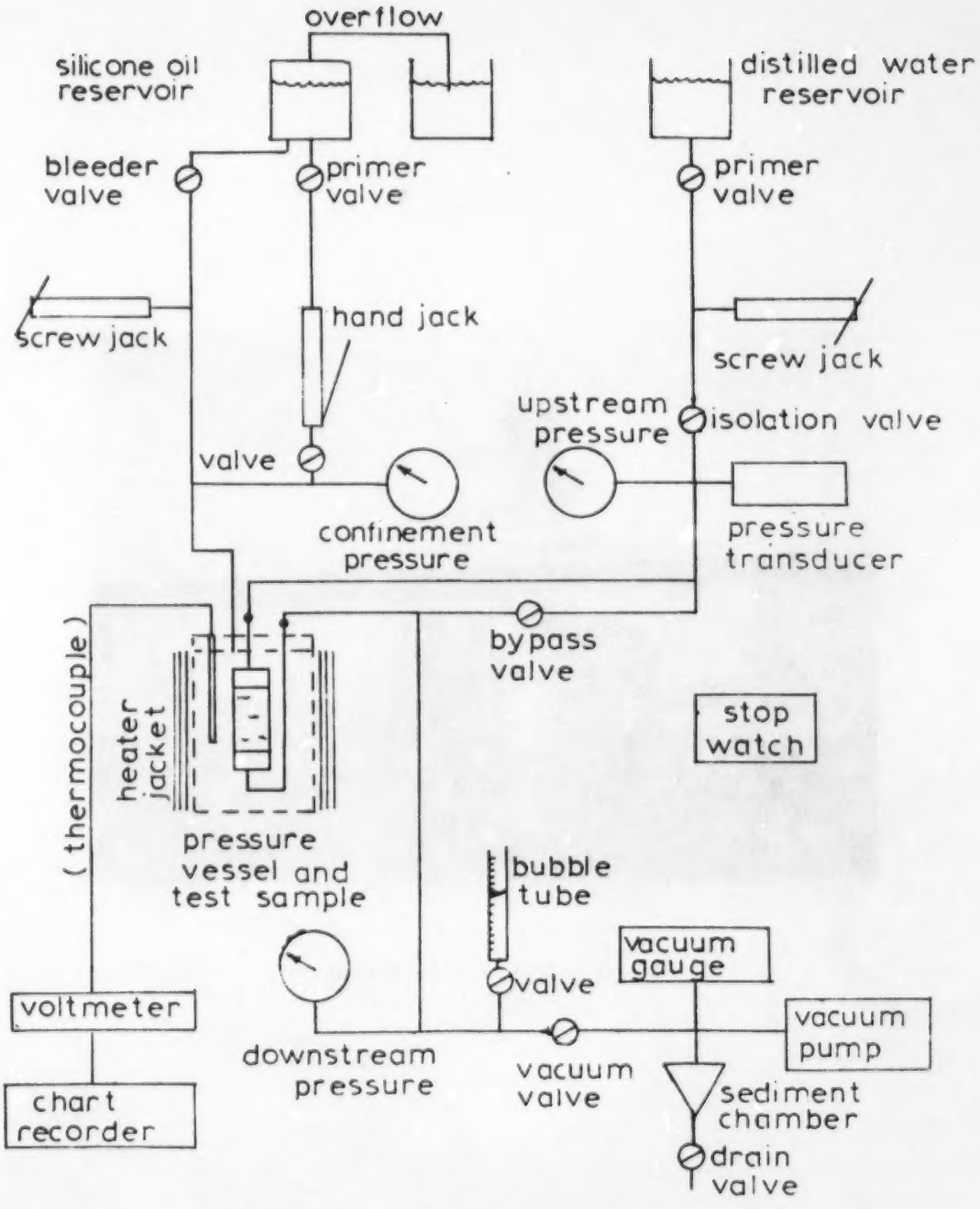

Fig. 2 - Apparatus schematic

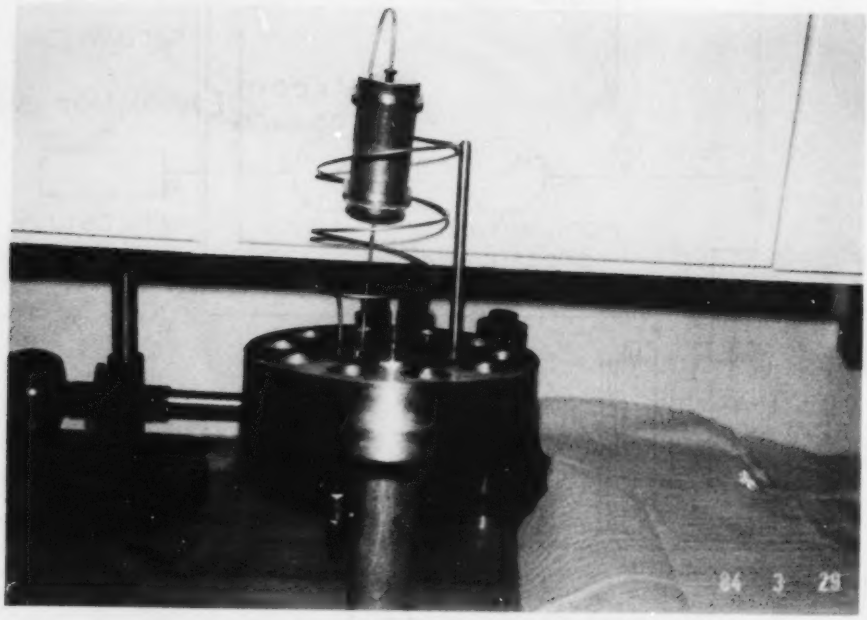

Fig. 3 - Test sample assembly